MODULE 1 Measurements and force

A physical can be defined as the characteristic property of a system that is generally quantified in terms of measurement.

The physical quantities that are independent of other physical quantities are called Fundamental quantities. The seven fundamental quantities, and their units are given the table.

Physical Quantities	Units	Symbol
Length	Meter	m
Mass	Kilogram	kg
Time	second	s
Temperature	Kelvin	k
Electric Current	Ampere	A
Luminous Intensity	Candela	cd
Amount of substance	Mole	mol

The physical quantities that cannot be defined independently and can be broken down into base quantities called **derived quantities**. These are dependent quantities.

Examples of derived quantities are force, pressure, acceleration, volume etc

Unit systems

a) C.G.S. system: It is the Gaussian system in which centimeter, gram and second are taken as three basic unit for length, mass and time respectively.

b) M.K.S. system: In it metre, kilogram and second are taken as the fundamental units of length, mass and time respectively.

c) **International system of Units (SI)**: A **complete metric system of units of measurement for scientists.** It has seven fundamental and two basic supplementary

Fundamental quantities are length (meter) and mass (kilogram) and time (second) and electric current (ampere) and temperature (kelvin) and amount of matter (mole) and luminous intensity (candela)k.s is used only in mechanics

Some important conversions

1cm= 10^{-2}m 1m=100cm= 1000mm

1m=10^{-3}km 1km=1000m

1mm=10^{-3}m 1nm=10^{-9}m nano=10^{-9}

1g=10^{-3}kg, 1kg=1000g

Giga = 10^{9}, 1Mega=10^{6}, 1deci=10^{-1}

Q.1: What are fundamental units?
Ans: Fundamental units are the units of fundamental quantities. These units are independent and can not be broken down into other units.
Q.2: What are derived quantities?
Ans: The quantities that can not be defined on their own and can be broken down in terms of the base quantities are called the derived quantities.
Q.3: What is the unit of amount of substance?
Ans: Mole is the SI unit of substance.
Q.4: Candela is the SI unit of which physical quantity?
Ans: Candela is the SI unit of luminous intensity.
Q.5: Compute the unit of velocity.
Ans: Velocity is a derived physical quantity.
velocity = distance time = distance time . Thus, the SI unit of velocity is m/s.

Errors in Measurements

The difference between the true value and the measured value of a quantity is known as the error of measurement.

1. **Systematic Errors:** arises due to instrumental errors, incorrect experimental techniques, and personal errors.

Instrumental errors: arise from the imperfect design or calibration of instruments, zero error of instruments, etc. *Examples: Zero error in vernier calipers or screw gauge and error due to measurement of length using a scale broken at one end*

Error due to incorrect experimental technique: occur due to inaccurate experimental procedures as well as external factors like pressure, temperature, humidity, wind, etc. Eg.- *measurement of body temperature by placing a thermometer under the armpit results in a lower temperature value than the actual value.*

Personal errors: arise due to personal bias, lack of proper setting of the apparatus, or individual's carelessness in taking observations. These types of errors are also known as observational errors. *Eg- when an observer holds his head towards the right (by habit) while reading the position of a needle on the scale, he introduces an error due to parallax*.

These errors can be minimized by using better instruments, improving experimental techniques, and avoiding personal bias

2. **Random Errors (Chance errors):** come from unpredictable changes in experimental conditions. It makes to give different results for same measurements taken repeatedly. Random errors are present in all experiments and are unpredictable. These errors are also called statistical errors and can be removed by statistical methods like averaging

The random errors can be reduced by repeatedly taking greater number of measurements.

3. **Least Count Error:** It is the error associated with the resolution of the instrument. The smallest value that can be measured by a measuring instrument is called its least count. The maximum possible error is equal to the least count. All readings or values are good only up to this value. For example, a vernier caliper has the least count of 0.01 cm and a screw gauge has a least count of 0.001 cm. **Using instruments of higher precision, improving experimental techniques, etc., we can reduce the least count error**.

4. **Absolute Error**

If $a_1, a_2, a_3, \ldots\ldots\ldots, a_n$ be the values obtained for a physical quantity 'a' in an experiment repeated '*n*' times, then the arithmetic mean of the values is taken as the true value given by

$$a_0 = a_{mean} = \frac{a_1 + a_2 + ... + a_n}{n}$$

The absolute error of a measurement is the difference between the individual measurement and the true value of that quantity denoted as$|\Delta a|$. The absolute errors in measurement values are

$$|\Delta a_1| = |a_0 - a_1|,\ |\Delta a_2| = |a_0 - a_2|,\ |\Delta a_3| = |a_0 - a_3|,....., |\Delta a_n| = |a_0 - a_n|$$

Absolute error $|\Delta a|$ is always positive.

The arithmetic mean of all absolute errors of all the measurements is taken as the mean absolute error of the physical quantity '*a*'.

$$\Delta a_{mean} = \frac{\Delta a_1 + \Delta a_2 + ... + \Delta a_n}{n}$$

The value of a physical quantity

$$a = a_{mean} \pm \Delta a_{mean}$$

5. **Relative error :** The ratio of mean absolute error, Δa_{mean} to the mean value, a_{mean} of the physical quantity measured is called the relative error.

$$relative\ \ error = \frac{\Delta a_{mean}}{a_{mean}}$$

6. **Percentage error:**

The relative error of a physical quantity expressed in percentage is called percentage error.

$$percentage\ error = \frac{\Delta a_{mean}}{a_{mean}} \times 100$$

Vectors :

Vectors : Physical quantities having both magnitude and direction. Eg: displacement , velocity, force, acceleration

Scalars : Quantities that have only magnitude, Eg: distance, speed, work, energy, power

Null vector/Zero vector: When the starting point and the finish point of a vector coincide with each other, it is known as a zero vector or null vector. The magnitude of such vectors is zero.

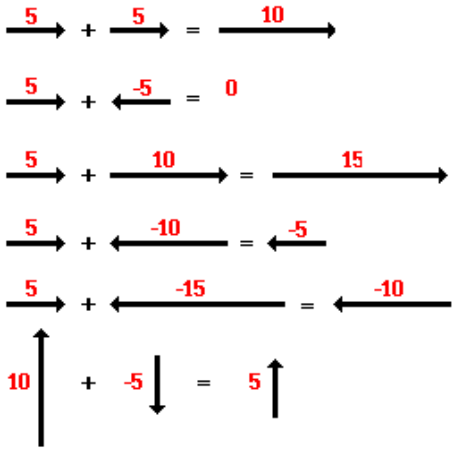
Unit Vector : A vector of unit magnitude is called a unit vector. $\hat{a} = \frac{\vec{A}}{|\vec{A}|}$

Collinear Vectors : Two or more vectors lying on the same plane. They can have same or different magnitude and direction.

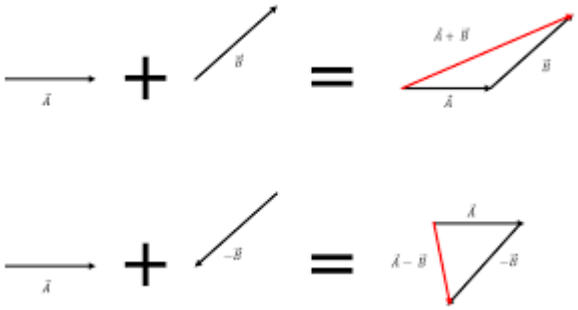
Equal vectors: Vectors having the same magnitude and the same directions are known as equal vectors.

Negative of a Vector: The negative of any vector is another vector with the same magnitude but opposite in direction.

Addition of vectors:

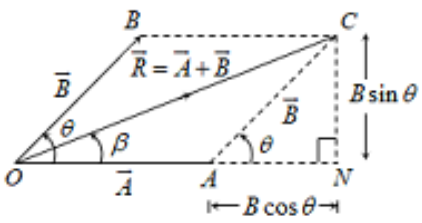


(a) Triangle method of Vector addition : If two vectors are represented in magnitude and direction by the two sides of a triangle taken in order, their vector sum is represented in magnitude and direction by the third side of the triangle taken in the reverse order.



(b) Parallelogram method of vector addition:

The **law of parallelogram of forces** : If two vectors acting on a particle at the same time be represented in magnitude and direction by the two adjacent sides of a parallelogram , their resultant vector is represented in magnitude and direction by the diagonal of the parallelogram drawn from the same point.



The magnitude of the resultant vector R is given by the expression

$$R = \sqrt{A^2 + B^2 + 2AB\cos\theta}$$

The direction of the resultant vector β with respect to A is given by

$$\beta = \tan^{-1}\frac{B\sin\theta}{A + B\cos\theta}$$

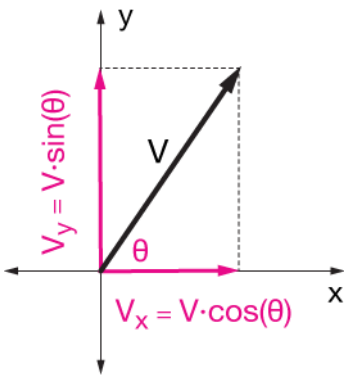
1. **When two vectors are in same direction /parallel, then θ=0, so cosθ=1**

Then R= A+ B

2. **If two vectors are in opposite direction, then θ=180, so cosθ=-1**
   R=A-B

Resolution of a vector: The process of splitting a given vector into two or more along different directions. These vecotors are called component vectors. In the figure below, The vector V is resolved in x and y directions with components V_x and V_y. $V= V_x+V_y$

With $V_x = V\cos\theta$, $V_y = V\sin\theta$



Kinematics:

Distance : The total length of the path travelled by a particle

Displacement : The shortest path length between the final position and the initial position of the particle.

Speed = distance/time .It is a scalar quantity with unit m/s

Velocity = displacement / time . It is a vector quantity with unit m/s

Acceleration(a) = Change in velocity/time

$a = \frac{v-u}{t}$ where v is the final velocity and u is the initial velocity. Its unit is m/s^2

Equation of motion: This gives the relations between displacement , velocity, acceleration and time.

$v = u + at$

$S = ut + \frac{1}{2}at^2$

$v^2 = u^2 + 2aS$

Dynamics:

Newtons First Law (Law of Inertia) : Everybody continues in its state of rest or of uniform motion along a straight line unless an unbalanced force acting on it.

Inertia : Inertia is the resistance of a body to any change in its state of rest or uniform motion along a straight line.

Momentum: Momentum is defined as **the quantity of motion of the body**. All objects have mass When it moves, then it has momentum. It is defined as the product of mass and momentum. P=mv

The momentum of a body at rest is zero,

Newton's second law. *the rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction of the force*.

force $\propto rate\ of\ change\ of\ momentum$

Force is proportional to the product of mass and acceleration $\propto ma$

F = dp /dt

Newton's third law : To every action, there is always an equal and opposite reaction.

If a body B exerts a force, F_{AB} on a body A, then the body A exerts an equal and opposite force, $_{BA}$ on body B.

$$F_{AB} = -F_{BA}$$

The main properties of action and reaction forces are:

a) Action and reaction are the simultaneously occurring pair of forces acting between two objects.

b) Forces always occur in pairs and a single force doesn't exist in the universe. This is an important property of forces.

c) Action and reaction are always equal in magnitude and opposite in direction.

d) There is no cause-effect relation implied in the third law. Both action and reaction occur at the same time. So, any of the two forces can be called action and the other reaction.

e) The action and reaction forces, though equal and opposite, never adds up to get zero. Action and reaction do not cancel each other since they act on different objects.

Law of conservation of momentum:

Total momentum before collision between two or more bodies is equal to total momentum after collision

$$force = \frac{Change\ in\ momentum}{time}$$

If the net force acting on the system is zero, then the change in momentum also becomes zero. Ie,

$$final\ momentum = initial\ momentum$$

Thus, the law of conservation of momentum states **that if the net external force acting on a system is zero, its linear momentum remains constant.**

$$F_{12} = m_1 \frac{(u_1 - v_1)}{t} \qquad F_{21} = m_2 \frac{(u_2 - v_2)}{t}$$

- According to Newtons third law $F_{12} = -F_{21}$

$$m_2 \frac{(u_2 - v_2)}{t} = -m_1 \frac{(u_1 - v_1)}{t}$$

$$m_2 (u_2 - v_2) = -m_1 (u_1 - v_1)$$

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

Ie., Total momentum before collision = Total momentum after collision

Recoil of the gun:

The backward motion of a gun when a bullet is fired from it is called the recoil of the gun.

It can be explained using the principle of conservation of linear momentum.

- The total momentum of the gun and bullet before firing is zero. Since no external force acts on the gun and the bullet, its momentum should be conserved.
- After firing the bullet moves with a velocity producing momentum in the forward direction.
- To balance the momentum change, the gun moves backward with a velocity, such that the total momentum is zero

Let M_g and m_b are masses of the gun and bullet respectively. Suppose, a bullet is fired from the gun with a velocity v_b and the gun recoils with a velocity V_g.

$$Total\ momenta\ before\ firing = 0$$

$$Total\ momenta\ after\ firing = M_g V_g + m_b v_b$$

By the law of conservation of momentum, the total momenta after firing must be equal to the total momenta before firing.

$$M_g V_g + m_b v_b = 0$$

$$M_g V_g = -m_b v_b$$

$$V_g = -\frac{m_b v_b}{M_g}$$

The negative sign shows that the **direction of recoil velocity of** the gun is opposite to the direction of the velocity of the bullet.

Rocket Propulsion

The principle behind rocket propulsion is the law of conservation of momentum (external force on rocket is zero and effect of gravity is neglected).

Matter is forcefully ejected from a system, producing an equal and opposite reaction on what remains.The momentum of the gases is directed backward.

For momentum to be conserved, **the rocket must acquire an equal momentum in the forward direction**. If the rocket carries all the materials needed for the combustion of its fuel, its propulsion does not require air, and it can move through empty space.

The increased forward momentum of the rocket is equal but opposite in sign to the momentum of the ejected exhaust gases.

Impulse

A large force acting for a short interval of time is called an impulsive force.

Impulse = Force x time

Unit= Newton second (Ns)

$$I = Ft = ma \times t = m\frac{(v-u)}{t}t = m(v-u) = mv - mu$$

Impulse = change in momentum

Examples of impulsive forces are
Kicking a football, Striking a nail with a hammer ,Striking a ball with a bat